

HEAVY MINERAL STUDIES By R. H. Morris and E. H. Lathram

The heavy minerals of approximately 1,400 samples of sandstone from northern Alaska, mostly from rocks of Cretaceous age, Composite chip samples were taken from outcrops and from cored intervals in wells. In outcrops one composite sandstone sample was taken for each 00-foot stratigraphic interval; shale units were not sampled. Sandstone layers in the wells were sampled at 10-foot intervals. The disaggregated sample material passing 80-mesh and retained on 235mesh screens was separated in bromoform (sp gr 2.79) and methylene iodide (sp gr 3.0) into light, medium, and heavy fractions. The grains were mounted in Canada balsam or aroclor.

The following discussion refers to the nonopaque heavy minerals in rocks ranging in age from Triassic to Pleistocene; the opaque heavy minerls were found to be nondiagnostic. For some zones biotite and muscovite which normally appear in the medium fraction, are included in the heavy fraction in this discussion, as they are somewhat diagnostic. Five criteria were used in recognizing and delimiting the mineralogic zones: (1) presence or absence of diagnostic minerals or mineral suites; (2) relative abundance of certain minerals (expressed here as percent of total nonopaque minerals; (3) percent of garnet grains etched in contrast to garnet grains with conchoidal fracture; (4) degree of rounding of mineral grains; (5) grain shape or form, such as euhedral and anhedral (ovoid) mineralogic zones have been found to be characteristic and useful in determining stratigraphic position and correlation, especially in the subsurface. Some zones identified only locally may possibly be more extensive, but this cannot be demonstrated because of facies changes from sandstone to shale. Fourteen major heavy-mineral zones have been recognized, including two that are time equivalent, and are discussed here from oldest

MINERALOGIC ZONATION

Rounded tourmaline zone.-A zone of subround to round tourmaline grains marks the Triassic and the lower part of the Jurassic sedimentary rocks in South Barrow Test Well No. 3. Several varieties of tourmaline are present--olive green, mauve, brown, and blue. More than 80 percent of the mineral suite is tourmaline. The remainder is zircon grains, which are ovoid, but the roundness may be influenced by the original crystal form as well as by wear during transportation. <u>Prismatic tourmaline zone.</u>--In the Jurassic rocks of Barrow and Cape Simpson a characteristic mineral suite consists of muscovite, zircon, garnet, hornblende, and tourmaline. Zircon grains are ovoid, garnet grains are etched, and hornblende grains are elongate and prismatic. The horn blende is bleached along the edges and cleavage traces. The tourmaline

brown prisms with fractured or pyramid terminations. Muscovite and zircon grains are abundant; hornblende and garnet are rare. Epidote zone .-- The zone of abundant epidote occurs throughout the Okpikruak formation. In most samples more than 70 percent of the heavy minerals is epidote and zoisite; the remainder consists of grains of etched garnet, olive-green, brown, or mauve tourmaline, augite, picotite, hypersthene, hornblende, and euhedral zircon. Most grains are fresh. Only outcrop samples of this zone have been examined and therefore the zone is not Augite zone. -- The augite zone is in the Torok formation and is recognized in well cores and outcrop samples. Augite grains constitute at least

50 percent of the heavy-mineral assemblage; also present are hornblende,

epidote, zoisite, tourmaline, garnet, hypersthene, picotite, and zircon

grains, comprising more than 50 percent of the suite, are olive-green or

The shape of the augite grains is determined largely by cleavage; thin delicate laths which have suffered little abrasion during transportation protrude from some of the grains. Zircon grains are euhedral and have a length to width ratio about 2.5:1. Other grains are angular. Zoned zircon zone. -- A zone characterized mainly by metamorphic minerals, but particularly by the presence of zoned zircon crystals, is present in part of the Torok formation, and in the Tuktu member and the lower part of the Topagoruk member. The base of the zone can be defined by the pres ence of chloritoid. The zoned zircon grains are usually doubly terminated, have a length-to-width ratio of about 3:1, and are yellow or very light Ovoid pink and colorless zircons are also present. Other minerals re garnet, tourmaline, picotite, biotite, andalusite, and muscovite. ew tourmaline grains have deeply colored ovoid cores enclosed by faint colored overgrowths with prismatic faces. The core and the overgrowth o an individual grain may be the same color or different colors. A large percent of the garnet grains are etched. Other grains are subhedral or angular. This zone is recognized in both outcrop and well samples. dral colorless zircon zone. -- The zone of euhedral colorless zircon the upper part of the Topagoruk member of the Umiat formation in

e Meade-Oumalik-Topagoruk area. The zircon grains have length-to-width ratios that may exceed 4:1; first-order prisms and pyramids are common Some pink zircon grains are present, and these have more complex crystal forms. Garnet, tourmaline, biotite, muscovite, and alusite, picotite, and ritoid complete the mineral assemblage. Andalusite grains are prismatic, with single terminations of complex pyramids, and many contain carbonaceous inclusions oriented parallel to the c axis. The biotite plates are deep brown or light rust brown. Only well samples have been examined. Glaucophane-hornblende zone.--The base of the glaucophane-hornblende zone is defined by the greatest depth at which glaucophane is encountered (2,981 feet in Umiat Test Well No. 1). In the Simpson area the top of the zone is marked by the base of the biotite zone described below. The zone s present in the upper part of the Topagoruk member of the Umiat formation zone and the euhedral colorless zircon zone are therefore stratigraphically equivalent. The mineral suite of this zone includes garnet, tourmaline zÍrcon, biotite, muscovite, andalusite, hornblende, glaucophane, augite epidote, picotite, and chloritoid. Garnet grains are pink or colorless and a majority of them are etched. Glaucophane grains are blue and lavender pleochroic laths with good cleavage. The hornblende laths are pleochroic deep blue to green and are rare to common. Both deep-brown and light-must rown plates of biotite are common to abundant but never constitute more han 40 percent of the suite. Samples from well cores and outcrops have

Biotite zone. -- In the Simpson area a zone containing dark-brown and light rust brown biotite flakes is present in the Seabee member of the Schrader Bluff formation. The biotite flakes, which are subhedral, are prominent in the bentonitic beds of this member, constituting more than 90 percent of the heavy-mineral assemblage. This zone is 100 feet in average hickness. The subordinate minerals are glaucophane, zircon, tourmaline, garnet, andalusite, muscovite, and chloritoid. This zone has been recognized only in Simpson Core Tests Nos. 13 to 28.

iotite flakes are abundant, averaging more than 40 percent but less than percent of the heavy minerals. Prismatic colorless andalusite is common ornblende laths differ from the hornblende in the glaucophane-hornblende sone by being pleochroic brown to green; they are rather fresh and have good cleavage. Garnet grains are pink or colorless, and most of them are ractured. Chloritoid, zircon, tourmaline, glaucophane, and picotite are also present. Only outcrop samples were obtained from this zone; therefore it is not shown in figure 19, B. Augite-biotite zone. -- The augite-biotite zone is restricted to the upper part of the Tuluga member of the Schrader Bluff formation. Less than

O percent of the heavy minerals are biotite plates, and of this the light rust-colored variety predominates over the dark-brown variety. Angular cleavage fragments of augite are abundant. More grains of garnet are fractured than are etched. Other minerals present in this zone are chloritoid, laucophane, muscovite, picotite, tourmaline, and zircon. Samples studied rom this zone are from outcrops only, so the zone is not included in Fractured garnet-glaucophane zone.--The fractured garnet-glaucophane zone is in the lower part of the Sentinel Hill member of the Schrader Bluff

dant heavy minerals. The top of the zone is marked by the top occurrence of glaucophane. Other minerals present are chloritoid, tourmaline, picoite, and zircon. This zone is recognized in samples from Sentinel Hill Fractured garnet zone. -- The zone containing abundant grains of fractured garnet is in the upper part of the Sentinel Hill member of the ader Bluff formation. The major difference between this zone and the garnet-glaucophane zone is the absence of glaucophane. Chloritoid, tourmaline, and picotite are present; zircon is slightly more common than in the garnet-glaucophane zone. Samples of this zone are from Sentinel Hill Core

Fractured pink and colorless garnet grains are the most abun

<u>Kyanite zone</u>.--This zone is restricted to the Sagavanirktok formation. It is characterized by the rare but consistent occurrence of kyanite laths, the shape determined by cleavage and partings. Other heavy minerals present are fractured and etched garnet, ovoid (round) and prismatic tourmaline blue-green hornblende, picotite, chloritoid, and euhedral, zoned, and ovoid zircon. Garnet, tourmaline, and zircon grains characteristic of older sedimentary rocks (described above) are present in this zone; therefore it is probable that at least some of the heavy-mineral fraction was derived by erosion of Mesozoic sedimentary rocks. As kyanite makes its first appearance in this zone and is a first-generation mineral, the zone is in part made up of detrital material from different source rocks. Only outcrop samples were examined. Rounded grain zone .-- A zone characterized by very well rounded grains of andalusite, garnet, glaucophane, epidote, chloritoid, biotite, muscovite hornblende, tourmaline, and zircon is characteristic of the Gubik formation

The high degree of rounding and the variety of the minerals present are the criteria for differentiation from all other zones. Samples of this zone

were obtained from the Simpson core tests, South Barrow wells, and outcrops.

AREAL AND SUBSURFACE OCCURRENCE For the most part, throughout the wells and outcrop areas studied, the heavy-mineral zones do not extend across the boundaries of stratigraphic units. An exception is the zoned zircon zone, which embraces the Tuktu memper and the lower part of the Topagoruk member and in the Barrow area may The stratigraphic relationships of the heavy-mineral zones are shown in figure 19. The epidote zone, representative of the Okpikruak formation, has been studied only in the Castle Mountain outcrop area. area, and from several test wells. In Simpson Test Well No. 1 the Toro rmation, in which this zone occurs, is largely shale and was not sampled refore figure 19 may not show the true vertical extent of the augite zone. The zoned zircon zone is the most persistent. In addition to it resence in most of the deep wells shown in figure 19, the zone can be raced west to the Kukpowruk-Kokolik Rivers area. At its western extremity hould be present in Topagoruk Test Well No. 1, but no cores were taken from sandstone within its estimated range. Southeast to Umiat and north to Barrow the zone thins owing to facies changes of sandstone to shale. The two zones of the upper part of the Topagoruk member of the Umiat formation are more or less equivalent in age but are separated geographiopagoruk area and probably extends westward wherever rocks of equivale

may have been carried northwestward by marine currents. The biotite zone of the Seabee member has been used in correlating Simpson Core Tests Nos. 13 through 28. In Fish Creek Test Well No. 1 and Sentinel Hill Core Test No. 1 the Tuluga member of the Schrader Bluff formation is shale; therefore no zones are shown on figure 19. B. Sandston beds of this member crop out, however, in and south of the Umiat area. the sandstone the biotite-hornblende-andalusite zone and the augite-biotit zone were identified. The kyanite zone occurs in outcrops of the Sagaanirktok formation along the Ivishak River and the east fork of the Shaviovik River. The Sagavanirktok formation is not present in the areas The samples of the rounded grain zone, representative of the Subik formation, are from several wells and from outcrop.

mineral assemblages of these two zones suggest derivation from different parts of the Brooks Range province. The boundary between these zones of

equivalent age trends northwestward, generally coincident with the mean

position of the shore line that existed when the upper sediments of the

pagoruk were deposited. Glaucophane and hornblende of the eastern zone

w-Simpson, Fish Creek, and Umiat areas. The differences in the heavy-

By George Gryc

Earlier reports on the geology of the Arctic Slope of Alaska (Smith age and correlation of the stratigraphic units. These lists are fairly comof the Cretaceous beds. The paleontologic work related to the current exploration program has been concentrated largely on Cretaceous rocks. Discussion of other stratigraphic units is here confined to such new information as has changed or added to knowledge of the general stratigraphy.

Rocks of Devonian age are widespread along the crest and on the south side of the Brooks Range. Small areas of Upper Devonian rocks (sheet 1, t of rocks mapped as Devonian by Smith and Mertie (1930). Prelimina: study of megafossils from these Upper Devonian rocks indicates that the fauna is related to Upper Devonian faunas of western Canada and China Fossils of Middle Devonian age were reported by Smith and Mertie (1930 from the Chandalar district on the south side of the Brooks Range but are not definitely, known north of the Range.

Mississippian. -- Fossils are abundant in the Lisburne limestone and somewhat less abundant in the Noatak formation. Fossils collected prior to 1930 from many localities in the Lisburne limestone and Noatak formation were listed by Smith and Mertie (1930), but no attempt was made to subdivid these formations on a faunal basis. Four major divisions of the Mississippian rocks are recognized on the basis of the large number of fossils collected during the present exploration program. Study of many stratigraphi sections has shown marked facies changes and close relationship of fossils

The Sadlerochit sandstone in the Canning River region was originally described by Leffingwell (1919) and was referred to the Pennsylvanian. 39 Smith (p. 32), on the basis of further study by Girty, referred the Sadlerochit sandstone to the Permian. Recent field work substantiates the tter determination. The formation has been traced west to the Ivishak River, where it either pinches out or changes in lithology. In the area of the upper Siksikpuk River approximately 100 miles west of the Ivishak River a sequence of beds has been mapped which in part may rrelative with the Sadlerochit sandstone of the Canning River area. These beds in the Siksikpuk River area contain corals that most closely resemble Permian forms. Beds that appear to be in continuous sequence, how ever, contain other fossils that indicate a possible age range from late

Mississippian to Triassic. Before 1944 Triassic rocks in northern Alaska were best known in the Canning River and Cape Lisburne areas. A few scattered outcrops had been mapped between these two areas. Recent field mapping has demonstrated a nearly continuous belt of Triassic rocks from the Okpilak River west to Cape Lisburne. Leffingwell (1919, pp. 113-115) named the Triassic rocks of the Canning River area the Shublik formation. This name is here applied to the entire belt of Triassic rocks in northern Alaska. The Shublik formation in the Canning River area is very fossiliferous and a rather complete fossil list is given by Leffingwell (1919, pp. 117-118). The fauna is characterized by abundant individuals of the pelecypods Monotis subcircularis Gabb and Halobia cordillerana Smith, and the brachio-pods Rhynchonella sp., Terebratula sp., and Spiriferina sp. Cephalopods are very rare. In the area between the Anaktuvuk and Utukok Rivers the

Triassic rocks contain abundant individuals of <u>Halobia</u> and <u>Monotis</u> and a few specimens of a pelecypod tentatively identified as <u>Claraia</u> sp. The monites include <u>Trachyceras</u>, <u>Arcestes</u>, and a poor specimen questionably referred to the genus <u>Ophiceras</u>. Megafossils from the subsurface of the Barrow-Simpson area include <u>Monotis</u>, <u>Halobia</u>, <u>Oxytoma</u>, and an ammonite questionably referred to <u>Tropites</u> (<u>Anatropites</u>). In many of the areas <u>Halobia</u> occurs with <u>Monotis</u>, and in South Barrow Test Well No. 3 the first <u>Halobia</u> occurs well above the first <u>Monotis</u>. In other parts of the world <u>Halobia</u> is supposed to mark the lower stage of the Upper Triassic (Karnian) and <u>Monotis</u> (Pseudomonotis) (Muller, 1938, p. 1893) the middle stage of the Upper Triassic (Norian). In the northern Alaska localities this does not appear to hold true. This was noted by Martin (1926, p. 102) for the earlier collections from northern Alaska as well as for other parts of Alaska. The occurrence of Halobia, Monotis, Tropites, and Trachyceras, however, establishes the presence of Upper Triassic rocks. The occurrence of questionable Claraia and Ophiceras may indicate that Lower Triassic rocks are represented. If this proves to be true, it will be the first established compressed for the course rocks in Alaska. be the first established occurrence of Lower Triassic rocks in Alaska.

The only previously known rocks of Jurassic age in northern Alaska were mapped in the Canning River area by Leffingwell (1919, pp. 119-125). These rocks were named by him the Kingak shale and the Ignek formation. The Kingak shale was believed to be Early Jurassic in age on the basis of occurrence of Pentacrinus cf. P. subangularis var. alaskana Miller, an index of the Lower Jurassic of England and Europe. The Ignek formation was questionably referred to the Jurassic and was believed to overlie the Kingak Recent work in the Canning and Shaviovik Rivers area has substantiated Leffingwell's published results. In addition to the Lower Jurassic Pentacrinus faunule, however, four other faunules are now recognized above it in the Kingak shale. They are, in ascending order: Pseudolioceras-Inoceramus lucifer; Arcticoceras; Gosmoceras; and Amoeboceras-Aucella bronni. These faunules represent the lower Bajocian, lower Callovian, upper Callovian, and upper Oxfordian to lower Kimmeridgian stages, respectively. a much more complete Jurassic section is present than had been previously reported. The Ignek formation is now believed to be Jurassic in part, but

sic rocks where such rocks had not been previously known. Cores from tes wells in the Barrow-Simpson area contain several genera of Early Jurassic including <u>Dactylioceras</u>, <u>Peronoceras</u>, <u>Amaltheus</u>, <u>Metaderoceras</u>, and <u>ma</u>. These fossils mark a zone approximately correlative with the Pentacrinus faunule of the Canning River area. Topagoruk Test Well No. 1 (sheet 1, fig. 1) has penetrated beds approximately correlative with the Amoeboceras-Aucella bronni and Pseudolioceras-Inoceramus lucifer faunules of he Canning River area. Upper and Middle Jurassic rocks are present in the upper Chandler and Anaktuvuk Rivers area. There <u>Aucella bronni</u> marks the Oxfordian-Kimmeridgian stages and <u>Pseudolioceras</u> the <u>Bajocian</u> stage.

Recent field work and drilling have established the presence of Jura

Okpikruak formation. -- The Okpikruak formation contains the typical Early Cretaceous (Neocomian) Aucella commonly referred to A. crassicollis (Keyserling). Specimens are rare but a few can be found in nearly all outcrops. They are generally poorly preserved and, although readily identifiable, vary widely in size and shape. The cephalopod Lytoceras has also been collected from this formation. In the Nimiuktuk-Kugururok Rivers area on the south side of the De Long Mountains, Aucella okensis Pavlon and Aucella crassa Pavlon have been collected from beds that probably represent a Cretaceous time interval earlier than that of the beds containing Aucella

Torok formation. -- The Torok formation is sparsely fossiliferous. A fish skeleton is the only megafossil so far found in the lower part of the formation. The basal several hundred feet of the upper part of the Torok formation contains an <u>Inoceramus</u> and the ammonites <u>Lemuroceras</u>, <u>Beudanticeras</u>, and <u>Cleoniceras</u>. <u>Aucellina</u> sp. is present in a thin zone approximately 1,500 feet above the base of the upper part of the formation. Strong radial costae distinguish <u>Aucellina</u> sp. from <u>Aucella crassicollis</u> of the Okpikruak formation but are similar to those of <u>Aucella bronni</u> of the upper part of the Kingak formation. Ralph W. Imlay states that the two are distinguishable "by determining the convexity and relative size of the two valves. In <u>Aucella bronni</u> the left valve is only slightly larger than the right valve and the forms tend to become broad and flattened during growth. In <u>Aucellina</u> sp. the left valve is much more convex than the right valve, its beak is much incurved over the smaller right valve, and the general form remains fairly convex during growth." Both forms commonly make up

Nanushuk group. -- The Nanushuk group has yielded two distinct faunal assemblages. The faunas tend to follow lithologic facies, which cross time lines. Gross vertical ranges, however, can be delimited in terms of lowest The lower megafossil assemblage occurs throughout the Tuktu member of the Umiat formation. Diagnostic fossils are Cleoniceras and Inoceramus n sp. (subcircular) (fig. 20, 1, 2). The genus Cleoniceras also occurs in the upper part of the Torok formation. Inoceramus n. sp. (subcircular) is characterized by a circular to subcircular outline and by irregular concentric ridges that commonly bifurcate or intercalate. The shell is generally higher than long; the beak, nearly terminal, rises above the hinge line and is slightly curved anteriorly; radial sculpturing is ab and concentric sculpturing is not well developed on the posterior The specimens that have been collected are not well preserved. but they appear to be closely related to  $\underline{I}$ .  $\underline{anglicus}$  Woods, a European form, and to closely resemble  $\underline{I}$ .  $\underline{bellvuensis}$  Reeside and  $\underline{I}$ .  $\underline{comancheanus}$  Reeside from the Cretaceous rocks of Colorado.

Inoceramus n. sp. and <u>Cleoniceras</u> are generally associated with such long-ranging generalized types as <u>Pecten</u> spp., <u>Tellina</u> sp., <u>Lucina</u> sp., <u>Nucula</u> sp., and <u>Dentalium</u> spp. Starfish remains and a few crinoid stems have also been collected. This fauna is found in fine- to medium-grained, dark-greenish-gray sandstone. Lenses of coarse sandstone and conglomerate are commonly intercalated with the fossiliferous beds. The fossils are generally scattered throughout the sandstone and rarely are concentrated in layers or "pockets." This fauna is exclusively marine and indicates an offshore marine and locally a littoral environment. Inoceramus n. sp. (subcircular), associated with carbonized wood fragments and pebbles, occurs in poorly defined lenses in sandstone in the Oolamnagavik River area. Fossils of organisms that normally live in differing environments also are in these lenses and include Dentalium; Pinn and other burrowing types; <u>Pecten</u>, a free-swimming form; <u>Volsella (Brachydontes)</u>, a brackish-water or marine form; <u>Inoceramus</u> sp., a near-shore form; a fresh-water <u>Unio</u>; and marine forms such as <u>Tellina</u> and <u>Protocardium</u>. Thus it seems that these fossils were transported and deposited in a nearshore environment. Changes in environmental conditions were probably rela-

The second distinctive megafossil assemblage of the Nanushuk group is in about the middle of the Topagoruk member of the Umiat formation. The characteristic fossil of this assemblage is <u>Inoceramus</u> n. sp. (linguiform) (fig. 20, 3). This <u>Inoceramus</u> appears to be restricted largely to one sandstone and conglomeratic sandstone unit and does not reach either the top or the bottom of the Topagoruk member. Associated fossils extend several bundred feat shows and below the renge of this Inoceramus. Many of eral hundred feet above and below the range of this <u>Inoceramus</u>. Many of these associated fossil forms are long-ranging types that extend down into Inoceramus n. sp. (linguiform) is characterized by the linguiform outline, its erect beak, asymmetric concentric ridges with well-defined axis of elongation, and poorly developed radial plications. Inoceramus n. sp. (linguiform) somewhat resembles the European forms I. crippsi Mantell and lingua Goldfuss. This faunal assemblage is more restricted in areal extent than the lower assemblage of the Tuktu member of the Umiat formation and is known only in outcrop areas. The fossil types of the two assemblages are closel related, and the preservation is very similar, namely, the internal and ex

ternal molds have very little original shell material remaining. The upper faunal assemblage of the Nanushuk group is found in a predominantly medium grained, yellow-red-weathering sandstone. Interbedded with the fossiliferous sandstone are conglomerate and minor amounts of coal, shale, and ironstone. Fossils are not abundant but are generally found in local accumula Inoceramus is commonly associated with Unio (fresh water), Myti (brackish water), and Tellina and Protocardium (marine). This mixture of forms from different environments, in a light-colored, well-sorted sandstone matrix, suggests a littoral environment. Colville group. -- The Schrader Bluff formation, the marine part of the lile group, is divided into three members. The lower two, the Seabee

megafossils except for a few long-ranging pelecypods, including fresh-water, most distinctive and readily identifiable fauna in the Cretaceous rocks northern Alaska. It is characterized by few species but abundant individuals that are generally well preserved. This zone is marked by Inoceramus labiatus Schlotheim, Watinoceras sp., Scaphites delicatulus Warren, and Boriss jakoceras sp. (fig. 20, 4, 5, 6, and 7). Other species of Inoceramus and Scaphites are probably present. Fish remains, especially scales and , are common. This fauna has a widespread areal distribution i the outcrop area and has been encountered in the subsurface in the Fish Creek and Simpson areas. In outcrop the fossils are associated with this estone beds or nodules in a black paper shale (oil shale). These rocks were probably deposited slowly in a relatively quiet offshore marine envi-

The Tuluga member of the Schrader Bluff formation contains the mos

diversified fauna in the Cretaceous rocks of northern Alaska. Fossils ar abundant and many genera are represented. This faunal zone is distinguished by Scaphites sp. and Inoceramus cf. I. lundbreckensis McLearn (fig. 20, 8,9). Associated forms are the pelecypods Inoceramus labiatus, Protocardium cf. P. borealis Whiteaves, Glycimeras sp., Panope sp., Telsp., Volsella sp., Corbula sp., Yoldia sp.; gastropods and Turritella (?); fish remains, worm borings, tracks h as Gyrodes sp. and Turritella (1); Ilsh remains, not and ce d trails. The index Inoceramus of this zone is very distinctive and ce d trails. The index Inoceramus of this zone is very distinctive and ce be recognized even in fragments. It is characterized by strong radial and concentric sculpturing (fig. 20, 9). Nodes or tubercules are developed at ntersections of the radial and concentric ornamentation. There is consi erable variation in the development of these features. Some appear as reg ular nodes, evenly spaced across the shell. In this respect the northern Alaska form resembles I. cardissoides Schrader, a European form. Other of the Alaskan forms show prominent tubercules developed chiefly along the posterodorsal ridge below the wing and thus resemble more closely <u>I. lund-breckensis</u> McLearn. Some specimens of <u>Inoceramus labiatus</u> of the <u>Seabee</u> member show a tendency toward the development of radial costae which tend to form nodes where they cross concentric ridges, and may indicate a relationship to the <u>I. lundbreckensis</u> type. Some of the generalized, long-ranging types of pelecypods such as <u>Panope</u>, <u>Tellina</u>, <u>Mytilus</u>, and <u>Yoldia</u> range into the overlying Sentinel Hill member of the <u>Schrader Bluff</u>

Fossils of the Tuluga member are in fine-grained, light-gray sandstone that contains much tuffaceous material and locally is laminated with thin layers of carbonaceous material. A few collections have been made from a ly sandstone and conglomerate, but these are restricted to local lens In the sandstone the fossils are both in layers along bedding planes and scattered through the sandstone. The pebbly lenses may represent local accumulations along the shore, but the predominant environment of this zone was probably offshore marine. Sediments were probably deposited at a rate than those of the Seabee member of the Schrader Bluff formation but not as rapidly as those of the Nanushuk group. Faunas of the Colville group differ markedly from faunas of the Nanushuk group both in type of fossils and in preservation. In the Colville group the fossils are commonly preserved as original shell material with color markings, whereas in the Nanushuk group internal and external molds are the predominant type of preservation. The two megafossil zones of the Colville group show a close relationship taxonomically, as do the two zones of the Nanushuk group.

Sagavanirktok formation .-- Marine megafossils and microfossils are not known to occur in the Sagavanirktok formation. Gubik formation .-- Marine megafossils are rare. Vertebrate fossils include remains of the mammoth, mastodon, horse, bison, and musk ox.

On the basis of recent collections of plant fossils and of collections made by the earlier workers, Roland W. Brown of the U. S. Geological Survey has made the following statement regarding floras of northern "The Early Cretaceous floras are characterized by relative scarcity of species. The forms represented are chiefly ferns, cycads, gingkos, and conifers that are not greatly differen from their Jurassic ancestors. These floras can be correlated

roughly with others in the United States, Canada, Greenland, "The Late Cretaceous floras included not only descendants of the Early Cretaceous ferns, cycads, gingkos, and conifers but also representatives of a new group, the flowering plants dicotyledons). Among the dicotyledons were primitive water

lilies, oaks, sycamores, and others not identified with ce

tainty. In general, most of these plants are of the kind tha

grow in or near streams and ponds and that indicate an adequate

vegetation was back from the basin of deposition and on higher

water supply in a temperate climate. What the nature of the

"There is little fossil evidence bearing on Cenozoic flora of the Arctic Slope of Alaska, but these floras are presumed to be of the same general type as found elsewhere in Alaska. Cenozoic floras are not as yet clearly differentiated from one another. Their total aspect, however, is strikingly modern, with species of metasequoia, gingko, hickory, alder, birch, oak, beech hydrangea, sycamore, cercidiphyllum, and viburnum. These, plus he presence of palms, suggest that the mild climatic conditions of the Late Cretaceous continued well into the Tertiary."

areas is uncertain, but it was probably coniferous.

MICROPALEONTOLOGY By Helen Tappan

The bulk of the core and outcrop samples from northern Alaska contains a somewhat restricted microfauna, both in quantity and in variety. The environmental factors that limited the foraminiferal assemblages were possibl local brackish-water conditions, suggested by the intercalated coal beds in the coastal facies (fig. 5, sheet 1); and generally rapid sedimentation and muddy waters, evinced by the lack of sorting and other graywacke characterstics inherent in the sandstone and shale of Cretaceous age. Only the simpler types of Foraminifera that could best adapt themselves to the relatively unfavorable conditions are present. Because of this ability they were also the geologically long-living forms, and very similar species ag pear in like facies throughout the Mesozoic and Cenozoic. A large percent f the Foraminifera found in northern Alaska are of arenaceous genera, and these are usually crushed and distorted in preservation. The calcareous genera are less common, including only simple and unornamented species; many are represented only by pyritic casts.

logic facies pattern, in which the facies boundaries generally do not coincide with the stratigraphic time "horizons." Thus the termination in range of a faunal assemblage may be due locally to a change of facies, the same assemblage ranging stratigraphically somewhat higher or lower in other areas. The best foraminiferal assemblages are generally found to the north in the well samples, and much of the near-shore and coastal facies prominent in the outcrop area is barren of Foraminifera. Less than one third of the species have been found in outcrop material. In some localities, bed of the near-shore and coastal facies contain charophyte oogonia and fresh-

Although the fauna is limited in any one place or bed, the large quantity of material examined from northern Alaska has yielded a fairly large number of species, approximately 350. About 8 percent of these are Triassic, 12 percent Jurassic, 60 percent Cretaceous, and 20 percent Pleistocene. As most of the species are yet undescribed, they are of value for correlation only within the northern Alaska area. Correlation with the very similar Cretaceous rocks of Canada can be made, however, on the basis of a few species of Foraminifera common to the two areas.

About two thirds of the species of Triassic Foraminifera belong to the Lagenidae and Polymorphinidae. Particularly characteristic are Lingulina alaskensis Tappan (fig. 21, 17), Nodosaria shublikensis Tappan (fig. 21, 16), and Astacolus connudatus Tappan. The calcareous species are poorly preserved, and some are represented only by pyritic casts. This fauna is found in the outcrops of the Shublik formation and in Simpson Test Well No. 1.

A distinctive Early Jurassic fauna occurs in the Kingak shale in the

Upper Cretaceous. -- In the Colville group, nonmarine beds of the Prince Creek formation intertongue with marine beds of the Schrader Bluff forma-

The nonmarine inland facies is barren of Foraminifera, and the

brackish-water coastal facies and marine facies contain a limited fauna of

simple Foraminifera, with a total of about 30 species. The arenaceous

formation of Manitoba, thus supporting the megafossil evidence.

in Lower Cretaceous strata.

such as Haplophragmoides and Trochammina.

Manitoba and the Lea Park shale of Alberta.

ish water, and no pelagic genera are present.

forms include <u>Haplophragmoides</u>, <u>Trochammina</u>, and <u>Verneuilinoides</u>, and the calcareous <u>Buliminidae</u> and <u>Rotaliidae</u> are present in greater variety than

The Seabee member of the Schrader Bluff formation contains a meage

fauna, dominated by the pelagic <u>Globigerina loetterlei</u> Nauss (fig. 21, 8) and <u>Gumbelina</u> sp. These species are the microfaunal basis for correlation with the middle part of the Lloydminster formation of Alberta and the Favel

The Tuluga member of the Schrader Bluff formation contains a domi-

nantly calcareous fauna of Rotaliidae and Buliminidae, including Neobulimina canadensis Cushman and Wickenden (fig. 21, 6), and Bulimina venusae Nauss (fig. 21, 7), as well as a few arenaceous species, such as Spiro-

plectammina mordenensis Wickenden (fig. 21, 5), by which it can be correlated with the Morden and Boyne members of the Vermilion River formation

of Manitoba and the lower part of the Lea Park shale of Alberta. Locally the near-shore facies is barren or contains merely a few arenaceous forms

the underlying Tuluga member in many respects, but it includes a narrow zone of the distinctive Ecoponidella strombodes Tappan (fig. 21, 4), about 1,000 feet above its base, as well as Trochammina ribstonemsis Wickenden. It also has a distinctive assemblage of about 40 species of radiolaria. It

s the equivalent of the lower part of the Riding Mountain formation of

The Gubik formation (Pleistocene) has a dominantly calcareous fauna,

consisting of such advanced forms as <u>Cribroelphidium arcticum</u> Tappan (fig. 21, 1), <u>Elphidiella sibirica</u> (Gdes) (fig. 21, 2), <u>Cassidulina teretis</u> Tappan (fig. 21, 3), and many species of <u>Elphidium</u>, <u>Rotalia</u>, and <u>Quinqueloculina</u>. An offshore environment is not necessarily implied by the

alcareous assemblage, as most of the genera are notably tolerant of brack

GEOLOGIC HISTORY OF THE ARCTIC SLOPE

lated to the history of a much larger area that embraces Alaska and adja-

ogic setting of NPR-4 since pre-Cambrian time; much geologic detail and

ent parts of Canada and Siberia. The historical interpretation here pre-

ocumentation have been omitted. This summary is derived from (1) results

ure on Alaska, Canada, and Siberia, much of which is based on reconnais-

recent exploration in northern Alaska; (2) study of the geologic litera-

ance work; (3) consultation with geologists who have worked in Alaska; and

4) new theories of sedimentation and tectonics that are still being devel-

the western half of the United States and Canada. Geologic belts in Alaska

Southern Alaska coastal ranges Pacific coastal ranges and

and subject to change as new information becomes available.

seem comparable to belts in the United States as follows:

Arctic Coastal Plain

interior Alaska, between

Alaska and Aleutian Ranges

and Nutzotin Mountains

and Talkeetna, Wrangell,

Brooks and Alaska Ranges

(including Seward Peninsula)

nagmatic or amagmatic geosynclinal belts.

Brooks Range

and valleys

as being of graywacke type.

Thus the history as described is in considerable part inferential

Geologic conditions in Alaska are similar in a general way to those in

The term "graywacke" used in this section denotes a rock characterized

.) lack of sorting as to grain size; (2) angular grains embedded in s

ions of wave and normal current action. Although graywacke is specifically

ne and generally dark matrix; (3) a composition nearly equivalent to tha

f the source rocks and commonly including nonresistant minerals and rock

ragments; and (4) lack of cross bedding, ripple marks, or other indica-

sandstone, and shale in geosynclinal association, and all are referred to

heir location the reader is referred to Alaska Map E of the United States

is suggested that the reader also consult Smith's professional

In the maps (figs. 22-25) two types of geosynclinal belts are recog-

Geological Survey and to the geologic map of Alaska in Smith's professional paper (1939), both of which also show adjacent regions of Canada and Sibe-

nized in which geologic conditions are basically different; they are the

magmatic geosynclinal belt and the amagmatic geosynclinal belt. Together they form a broad geosynclinal tract that lies between the Pacific Ocean to

the south and west and a stable platform region to the north (Barrow platform) and east (Canadian shield). These belts contain great thicknesses of

predominantly marine sedimentary rocks that maintain lithologic similarity

position and in rock characteristics: (1) Cambrian through Silurian, (2) Devonian through Permian, and (3) Triassic into Early Cretaceous. In pass

ing from stage 1 to stage 2 the belts shifted markedly to the north and

acific Ocean, is characterized by submarine volcanic rocks that are lo-

in some stratigraphic sequences carbonate rocks, chert, and shale, as well

s the volcanic rocks, predominate, and record tectonically quiescent con-

ditions of deposition. In others volcanic rock and chert are associated

type, probably derived from island arcs within the geosynclinal bel

with great thicknesses of conglomerate, sandstone, and shale of graywacke

record tectonically active conditions of deposition. During orogenies the magmatic geosynclinal belt is the seat of deformation, locally intense and

cluding metamorphism, and of batholithic intrusion and mineralization.

The amagmatic geosynclinal belt, which is approximately the same as

he "miogeosyncline" of Stille and Kay, is on the platform and shield side

f the broad geosynclinal tract. The rocks differ from those of the mag-

cally very thick and by deposition in multiple geosynclines, mostly of the type termed "eugeosyncline" by Stille (1941, p. 15) and Kay (1947, p. 129)

Three stages are recognized in which the geosynclinal belts differ in

east at the expense of the stable region. After an Early Cretaceous orogeny, geologic conditions changed; the younger geosynclinal and basinal rocks are discontinuous in extent, variable in lithology, and cannot be classified as

The magmatic geosynclinal belt, which bordered and extended into the

a type of sandstone, these characteristics are shared by conglomerate,

umerous geographic features are mentioned that are south of

rooks Range and are not included in the geologic map of sheet 1.

Great Plains

Rocky Mountains

Sierra-Cascade belt.

Basin and Range and Plateau

tains and Sierra-Cascade belt.

The geologic history of the Arctic Slope is best understood when re-

The Sentinel Hill member of the Schrader Bluff formation is similar to

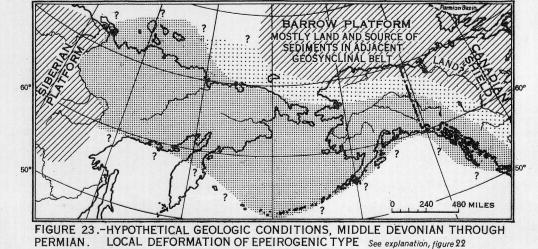
Simpson and Barrow wells. It consists of a number of Lagenidae, includin species of Nodosaria, Dentalina, Marginulina, Marginulinopsis, and Citharina. Arenaceous forms include Haplophragmoides barrowensis Tappan (fig. 21, 15), Ammodiscus, Reophax, and Ammobaculites. No Foraminifera of Early Jurassic age have been found previously in rocks in North America. Some sparsely fossiliferous Middle and Upper Jurassic strata have been found in the outcrop area and in Topagoruk Test Well No. 1. The microfauna from these strata is somewhat less varied than that of the Middle and Upper Jurassic of the western interior United States. Lower Cretaceous. -- The Okpikruak formation (Neocomian) contains very few microfossils, with only a few simple species of Bathysiphon, Trocham-

Shale of the Torok formation (at least partly Albian) and of the Tuktu member (Albian) of the Umiat formation are similar faunally; shale constitutes nearly all of these two units in the coastal plain and in the tion in the outcrop area contains much sandstone and conglomerate and i mostly barren of microfossils. In its outcrop area the Tuktu member of he Umiat formation is more sandy than the underlying Torok formation, inludes sandstone of inshore facies, and contains fewer microfossils. Only simple species of Haplophragmoides, Trochammina, Verneuilinoides, and others, many of which cannot be distinguished from those of the Upper Cretaceous in similar facies, are present. In the shaly facies, such as is tensity northward across the belt. ncountered in the wells, the fauna is more varied. Typical Albian forms include Gaudryina nanushukensis Tappan (fig. 21, 12) and species of Ammodiscus and Miliammina. A few calcareous species occur; most of them are lagenids, such as Marginulinopsis umiatensis Tappan (fig. 21, 13), and simple species of Lenticulina, Dentalina, and Vaginulina; a few are rotalids, such as Discorbis. In general the fauna is more restricted in character than faunas of Albian age in other regions.

form and shield area probably nowhere exceed 5,000 feet in thickness. There is no definite megafossil evidence of the age of the Topagoruk member of the Umiat formation of northern Alaska nor of the equivalent rocks in Canada. These rocks in Alaska and Canada may be either late Albian r early Cenomanian in age. The rocks outcropping in the foothills area at Simpson and Barrow, which penetrated basement rocks of probable pre that are equivalent to the Topagoruk member comprise the nonmarine Hatbox tongue, which contains charophyte oogonia, and marine strata that contain only simple, long-ranging arenaceous species of Foraminifera that also oc-Cambrian age; and they have not been found in the Canning Rive where Mississippian rocks are in contact with the metamorphic Neruokpuk formation. This formation may be entirely pre-Cambrian; if it include cur in the underlying strata. In the coastal plain, the Topagoruk member is more typically offshore in facies and contains a greater number and variety of Foraminifera than any other stratigraphic unit in northern Alaska. It here contains a total of about 100 species, although seldom do more than 10 or 15 species occur in a single sample. The Topagoruk member s correlative with the Asheville formation of Manitoba and the Lloydminster rcupine River, in the southern part of the Brooks Range, and in the formation of Alberta. Tritaxia manitobensis Wickenden (fig. 21, 9), Ammobaculites tyrrelli Nauss (fig. 21, 11), Miliammina manitobensis Wickenden, and Haplophragmoides collyra Nauss are some of the more distinctive species in this zone in Canada. A fairly large number of calcareous species is al-Seward Peninsulá. Carbonate rocks are conspicuous at all these places time of the orogeny that followed Silurian deposition. present, including simple species of the Lagenidae, Buliminidae, and Rotaliidae, such as Discorbis stictata Tappan (fig. 21, 10).

Paleozoic time. Lower Paleozoic rocks are but slightly deformed and cally are almost flat lying in areas little affected by Mesozoic and Cenozoic deformation, such as along the Porcupine River, in part of the Seward ninsula, and in the Chukotsky Peninsula of Siberia. In the southern part f the Brooks Range, rocks of this age lie along the center of an Early retaceous orogenic and intrusive belt, which may explain why they are more nighly deformed and metamorphosed than Devonian and Mississippian rocks in the northern part of the Brooks Range. MIDDLE AND LATE DEVONIAN, CARBONIFEROUS, AND PERMIAN HISTORY

this belt. Deposition, largely marine but in part continental, was in ate generally are not of graywacke type; this and other sedimentary feaures suggest weak rather than strong tectonic movements, although moderate o great thicknesses of rocks are involved.



Marine Devonian and Mississippian strata are widespread, are several thousands of feet thick, and at many places contain basaltic flows, tuff, and breccia of greenstone type. They comprise fossiliferous limestone, black shale and slate, great thicknesses of chert, and some quartzite and chert conglomerate. Devonian and Mississippian rocks appear to be strucsippian and Pennsylvanian or younger rocks. Pennsylvanian strata have been found only near Eagle, are about 5,000 feet thick, and consist of nonmarine shale, sandstone, and conglomerate, with one reported bed of coal. Marine Permian rocks have been found in a few localities in interior Alaska and probably are more extensive in southern Alaska; they consist of fossiliferous limestone and volcanic rocks, primarily basaltic lava, tuff, breccia,

in Alaska were deformed in late Paleozoic time. No intrusive rocks, other than possibly a few small ultramafic and mafic bodies, are recorded. In some areas the absence of units of late Paleozoic age indicates erosional unconformities both within and at the top of the sequence. In several places Mesozoic rocks rest with approximate structural conformity on Paleo-

Amagmatic geosynclinal belt. -- Sedimentary rocks of late Paleozoic age town in the Brooks Range and in the Southern Foothills section of the Arcc Foothills province of Alaska are part of the amagmatic geosync elt of late Paleozoic time. They are believed to aggregate many thousands of feet in thickness, to be predominantly marine, and to thin and disappear y northward convergence, overlap, or truncation in the Coastal Plain province, that is, within the area of the Barrow platform. In the Canadian part of this belt Carboniferous rocks disappear at the edge of the platform and are not represented in the Mackenzie River region, where Devonian rocks underlie Cretaceous rocks. Submarine lavas, so commonly interbedded with e sediments of the magmatic belt, are absent in the amagmatic geosyn-

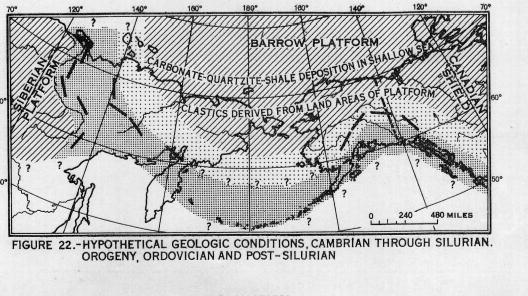
sissippian strata, suggests that marine waters of this belt had open con of the tremendous quantity of silica deposited in both geosynclinal belts. Although Mississippian rocks include some shale and quartz sandstone, they are largely limestone and chert. It is quite possible, however, that Misissippian as well as the more clastic Devonian rocks become increasingly lastic northward within the geosyncline, toward their source in land areas of the platform and shield. Upper Paleozoic (Devonian through Permian) clastics are believed to have been derived in considerable part from a platform or shield area to the north because: (1) In the Canning River reion of Alaska the Sadlerochit sandstone of Permian age grades northward gists of Imperial Oil Co., Ltd., have noted in the Mackenzie River region which led them to infer a northerly source. (3) A zone in the Lisburn limestone (Mississippian) contains quartzose and feldspathic sandstone in northerly exposures in the Foothills province and consists of bioclastic limestone to the south in the Brooks Range. (4) Upper Paleozoic sandstones are predominantly of quartzite type, suggesting derivation from a low-lying and decayed stable region of large extent. Other clastic types suggest a more local source, possibly in land uplifted within the geosynclinal belt Arctic Ocean area north of Siberia and Alaska. As noted above, there is evidence of a northerly source of sediments in Alaska and Canada. Therefore, it is believed that the Barrow platform and the adjacent part of the Canadian shield constituted a landmass that was undergoing erosion during much of late Paleozoic time. Local basins of deposition probably were esent in the platform and shield region. Recent geophysical work indicates the presence of Paleozoic rocks in the Arctic Coastal Plain of Alaska

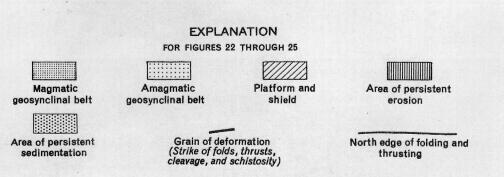
south, probably underwent only epeirogenic movements during and at the end of late Paleozoic time. Thus warping, truncation, and erosional unconformities are probable, but marked angular unconformities are unlikely. LATE TRIASSIC, JURASSIC, AND EARLY CRETACEOUS HISTORY (THROUGH EARLY ALBIAN) Magmatic geosynclinal belt. -- Linear geosynclines were developed at different times and places in this belt and were filled with sediments from tions and insufficient information, delineation of land and sea areas is at present impossible. Sandstone and conglomerate are mostly of graywacke type. Pyroclastic deposits and submarine lava are abundant, as is chert,

presence, in places, of quartzite derived from the platform and shield rerock and chert, represents times of tectonic quiescence. During times of Instability and orogeny, marine sediments of graywacke type, which were generally not accompanied by lava flows or chert, were deposited in considerable thickness. These sediments were derived from adjacent linear land areas that separated the two geosynclinal belts. During a given amagmatic geosynclinal stage the belt was distinguished by relative lack of igneous intrusion and mineralization and by less intense orogenic deformation effects of which died out to the north and east before reaching the platform and shield region. Amagmatic geosynclinal rocks of early Paleozoic age were highly deformed and intruded during Mesozoic time, when magmatic geosynclinal conditions were superimposed on amagmatic geosynclinal rocks. CAMBRIAN, ORDOVICIAN, AND SILURIAN HISTORY Magmatic geosynclinal belt. -- Great thicknesses of shale, sandstone, and conglomerate, all of graywacke type, as well as limestone, tuff, lava

and chert, accumulated in marine troughs. Clastics probably were derived mostly from volcanic island arcs within the geosynclinal belt (fig. 22). FIGURE 24-HYPOTHETICAL GEOLOGIC CONDITIONS, LATE TRIASSIC THROUGH EARLY Alaska, they very likely were deposited in the Alaska Range area and southward to and possibly beyond the present coast, where evidence of their ex-CRETACEOUS (EARLY ALBIAN):OROGENY, JURASSIC AND EARLY CRETACEOUS (ALBIAN) istence was obliterated by Mesozoic and Cenozoic sedimentation, orogeny, Silicic to mafic igneous intrusives of early Paleozoic age are known in the Siberian part of the magmatic geosynclinal belt, but have not been recognized in the Alaskan or Canadian parts. It is significant, however,

that in southeastern Alaska conglomerate and sandstone of Silurian through Triassic age contain plutonic igneous detritus, locally in abundance. is possible that this detritus was derived from intrusives formed at the time of early Paleozoic orogenies. A Late Ordovician orogeny, of which there is evidence in southeastern Alaska and in British Columbia, affected he magmatic geosynclinal belt, as did a later orogeny that followed Silurian and preceded Middle Devonian sedimentation. In parts of the belt





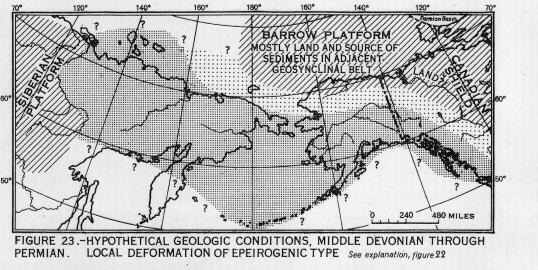
Amagmatic geosynclinal belt .-- Rocks probably equivalent to the Belt Ordovician, and Silurian ages were deposited in geosynclinal hickness in a belt that parallels the Alaska Range and lies mostly between it and the Yukon River. This belt of rocks may be continuous through Yukon Territory with the geosynclinal belt in British Columbia, Idaho, western Montana, Nevada, and western Utah, which contains rocks of these ages. Sedimentary rocks of early Paleozoic age that are probably at least 20,000 feet thick are Cambrian, Ordovician, and Silurian. The Cambrian rocks are largely limestone, with minor amounts of black shale, which have been identified in Alaska only north of the Yukon River near Eagle; the Ordovician rocks are extensive and comprise dark-gray to black slate, argil lite, chert, graywacke, quartzite, and limestone, and the Silurian rock are largely limestone and dolomite. The rocks are believed to thin and change in facies northward in the geosyncline and on a broad early Paleo-zoic shelf to the north, where carbonate rocks predominate even in the Ordovician system, as on the Seward Peninsula and along the Porcupine River.

t Siderian parts of this geosynclinal belt. Graptolitic states appear has great linear persistence, through Canada, Alaska, and Siberia.

Opi I for the belt are the Fossil Creek volcanics (mafic lava, tuff, and ecci.) of Ordovician age north of Fairbanks. The amagmatic geosynclinal belt was deformed but apparently not intruded during the orogeny that followed Silurian sedimentation. The deformation probably diminished in in-Platform and shield area. -- Parts of the early Paleozoic stable region, which probably included much of the present Arctic Ocean, were subjected to

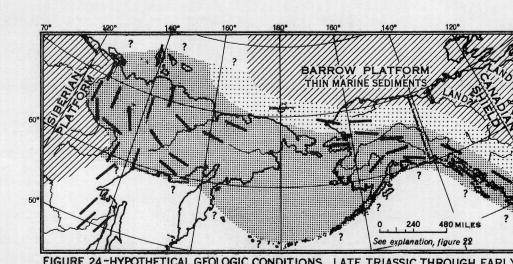
erosion and supplied sand and mud to shallow marine shelves and basins. Limestone, however, is the predominant rock type. Sandstone is of quartz-ite type, in contrast with the predominant graywacke of the geosynclinal belts. Cambrian, Ordovician, and Silurian sedimentary rocks in the plate Brooks Range in Alaska. They were not encountered in deep test wells Paleozoic rocks, they probably are post-Silurian in age. The absence of carbonate rocks and other lithologic features of the Neruokpuk formation strongly suggests that Cambrian, Ordovician, and Silurian rocks are not represented. Lower Paleozoic rocks are known to the east in the Richardson intain area of Canada; to the west in Siberia; and to the south along the erly Paleozoic rocks may have been extensively deposited and then eroded from part or most of northern Alaska, possibly by regional emergence at the

Magmatic geosynclinal belt. -- During late Paleozoic time the magmatic geosynclinal belt expanded northward nearly to what is now the southern margin of the Brooks Range (fig. 23). Thus more than half of Alaska lay in



In the Brooks Range the Devonian rocks include considerable sandstone and shale, as well as limestone. Chert, which is conspicuous in the Missouth of Barrow and Simpson, that is, along the southern margin of the in-

The platform and shield area, like the geosynclinal belts to the



The earliest Mesozoic deposits known in Alaska are marine Upper riassic rocks, which were deposited in considerable thickness in south-astern Alaska, in south-central Alaska in and south of the Alaska Range, nd in southwestern Alaska south of the Kuskokwim River. In these regions Triassic rocks consist mostly of argillite, chert, lava, pyroclastics, and dense limestone. Upper Triassic rocks with similar fauna were deposited in northern Alaska, and it is probable that they were also deposited in most of interior Alaska. In the interior region they have been identified only on the Christian River 75 miles north of Fort Yukon and at a locality ong the Yukon River downstream from Eagle, where they are only a few huned feet thick and comprise dark shale, including oil shale, and limestone. These rocks may have been largely eroded from interior Alaska by Jurassic sediments were deposited in great thickness in southeastern Alaska, south-central Alaska in and south of the Alaska Range, and possibly in southwestern Alaska. Shale, sandstone, and conglomerate of graywacke

type were deposited, together with submarine lava, pyroclastic rock, chert,

and limestone. These rocks were deformed and locally metamorphosed during furassic orogenies and also by large batholithic intrusives. Ultramafic

odies also were emplaced; mineralization was extensive during Jurassic

Jurassic rocks have not been reported in most of interior Alaska between the Alaska Range and Brooks Range. This area may have been an eastending Jurassic land area analogous to and possibly continuous with the Mesocordilleran geanticline of the United States and Canada. The conditions of geosynclinal sedimentation, extrusion, deformation, and intrusion that existed in southern and southeastern Alaska during rassic time spread northward into interior Alaska during Early Cretaceous time; they were terminated, probably in Albian time, by a profound oroge and extensive batholithic intrusion and mineralization. The northward spreading of these conditions in Alaska in Early Cretaceous time seems analogous to the advance, in the United States, of similar conditions eastward from the Pacific coastal area, to which they had been restricted in Jurassic time. Lower Cretaceous rocks, in part Aucella bearing, were deposited in considerable thickness in the Kuskokwim, the Koyukuk-Kobuk, and the Yukon-Tanana Rivers regions. They consist of slate, argillite, chert, basaltic lava, tuff, tuffaceous graywacke, and thin beds of limestone. Thus, in Early Cretaceous time the magmatic geosynclinal belt occupied most of the area of Alaska south of the Brooks Range. At the end of this episode of sedimentation much of this vast area was deformed, and the rocks were locally metamorphosed. Probably most of the extensive intrusion and mineralization in the Yukon-Tanana region, Baird Mountains of the Brooks Range, Koyukuk basin, and Seward Peninsula took place at the time of this

Lower Cretaceous rocks were deposited, deformed, and intruded is represented in much of northeastern Siberia east of the Siberian platform. I is highly mineralized region geologic conditions are similar to those i Alaska south of the Brooks Range and in the United States and Canada west Amagmatic geosynclinal belt. -- The amagmatic geosyncline of early Mesozoic time was about 150 miles in width, trended east across northern Alaska, and existed in what is now the northern border of the Brooks Range, the Arctic Foothills province, and the southern part of the Arctic Coa province. Four marine formations were deposited in this geosyncline: Shublik formation (Upper Triassic), the Kingak shale (Jurassic) kpikruak formation (Lower Cretaceous, Neocomian), and the Torok formation

The broad magmatic geosynclinal belt in which Triassic, Jurassic, and

(Lower Cretaceous, probably Aptian and early Albian). These formations together attain a maximum thickness of about 15,000 feet in the southern part of the Foothills province. At Oumalik Test Well No. 1, in the northern 8,000 feet and are believed to be underlain by the Jurassic and Upper Triassic rocks of the Shublik formation are several hundred feet thick where exposed along the north front of the Range. Here they include Monotis- and Halobia-bearing shale, in part oil shale, limestone, and chert. The faunal and lithologic similarity to the Triassic of interior and southern Alaska suggests continuous deposition across the Brooks Range area. The Jurassic geosynclinal sediments probably were derived mainly from the south. from the inferred Jurassic Mesocordilleran geanticline in interern Alaska as a subsurface formation in the Coastal Plain and the northern part of the Foothills province. At the type locality it is dark shale with siltstone and ironstone interbeds; fossils occur in some of the numerous concretionary zones and indicate that Lower, Middle, and Upper Jurassic

rocks are present. Jurassic rocks probably equivalent to the Kingak shale are exposed in the Richardson Mountains of Canada, between the Mackenzie River and the Canada-Alaska border. Upper Jurassic rocks probably equivalent to part of the Kingak are exposed at a few places in the southern part of the Foothills province south of Umiat. These marine rocks consist of sandstone and shale, lenses of breccia, thin coquinoid limestone beds, and thick beds of chert (or silicified tuff). The breccia lenses imply that at least part of the Jurassic sediments were derived locally. The Okpikruak formation is exposed extensively in the southern part of the Foothills province and locally in the northern part of the Brooks Range. The maximum measured thickness is about 2,000 feet. Species of <u>Aucella</u> indicate Neocomian age. The formation consists of shale and sandstone, show-

ing rhythmic alternation of relatively coarse and fine layers, and of conglomerate. These sediments probably were derived from land in the Brooks Range area, the emergence of which may have begun in Jurassic time and culminated in late Early Cretaceous time in the formation of the ancestral The Torok formation is extensively exposed in the southern part of the Arctic Foothills province, where it attains a maximum thickness on the order of 10,000 feet. Fossils are rare; Aptian as well as early and middle Albian probably are represented. The lower part of the formation is largely shale, but the upper and thicker part comprises shale, sandstone,

and conglomerate of a graywacke type that implies very rapid sedimentation under orogenic conditions ("flysch") in a marine foredeep. The composition of sandstone and conglomerate of the Torok formation indicates deri vation from a mountainous area, the contemporaneously formed early Brooks Range, where Carboniferous, Triassic, and Jurassic rocks, with their abundant intrusive rocks were exposed. The Triassic, Jurassic, and Lower Cretaceous (Okpikruak) formations are believed to be approximately conformable structurally, but local ang unconformities are indicated between the Okpikruak and Torok formations

and within the Torok formation. Local, relatively small-scale deformation probably took place in Jurassic and early in Cretaceous time, but the major Mesozoic orogeny probably did not take place until Albian time. The Albian deformation was more intense in and south of the Brooks Range than in the Arctic Foothills province, where a major extensive angular unconformity seems lacking. The orogeny is reflected in the character of the upper part Sills, dikes, and stocklike bodies of mafic and intermediate igneous rocks are numerous in Mississippian and Triassic formations and also occur n the Jurassic rocks, including Upper Jurassic. They have not been recognized as intruding the overlying Cretaceous Okpikruak, Torok, or younger formations. Therefore Late Jurassic volcanism has been inferred, primarily intrusion but possibly including extrusion. That the early Mesozoic geo-

syncline in the Arctic Slope region was, however, fundamentally amagma is indicated by the following: (1) granitic intrusives of this age have not been found; (2) lavas are absent or scarce; (3) the mafic rocks are not of greenstone type, which with its spilitic, ellipsoidal, and other distincve features charácterizes the magmatic geósynclinal beit; and (4) minerlization is rare. The granitic intrusives and mineralization in the area east of the Canning River are believed to be older than Mesozoic. The conditions and events as described for this geosyncline in Alaska seem to apply to the comparable belt in Canada and in Wrangell Island north of the Siberian mainland. In fact, the stratigraphy, paleontology, and structure of the rocks on Wrangell Island are remarkably similar to those along the north front of the Brooks Range. Platform and shield area. -- The four formations described above for the ynclinal belt must thin and in part wedge out, by convergence, trunca-

tion, or overlap, northward from the Oumalik deep test to deep wells at Barrow and Simpson, which are in the platform area. In South Barrow Test Well No. 3 and in Simpson Test Well No. 1, nearly flat-lying Triassic and Lower Jurassic rocks together are only about 1,000 feet thick and rest on basement rocks probably pre-Cambrian in age. Middle and Upper Jurassic rocks, included in the Kingak shale in the Canning River region, are not present. In South Barrow Test Well No. 1 Triassic and Jurassic rocks are absent, and strata believed equivalent to the Torok formation rest on base-Triassic and Jurassic rocks in the Barrow and Simpson test wells are platform facies and different from equivalent rocks in the geosyncline.

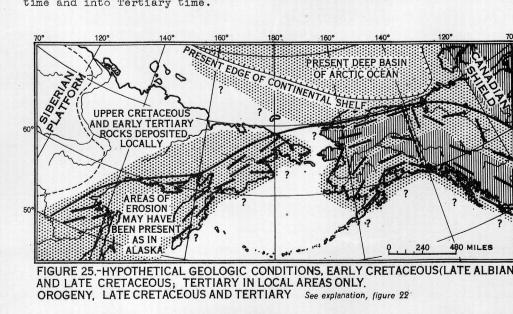
The Triassic is represented by fossiliferous limonite colite, limestone, and glauconitic calcareous siltstone. The Jurassic rocks consist of fossiliferous glauconitic sandstone and shale. The source of the clastic maerial probably was low land areas of the platform, rather than from the south. Rocks of early Mesozoic (pre-Albian) age are not represented in most of the Mackenzie River region, adjacent parts of the Canadian shield. westerm arctic islands of Canada. This region probably was a land phase In the Barrow, Simpson, and Topagoruk test wells the basal Cretaceous unit is approximately flat lying and is dark shale containing rounded grains, up to pebble size, of chert and quartz. At Barrow this unit is

out 600 feet thick. Fossils indicate equivalence to part of the Torok Well No. 1 apparently wedges out northward and is not represented in holes at Barrow, Simpson, and Topagoruk. is a shale unit characterized by extreme scarcity of microfossils and mega-fossils and by initial dips, principally north and generally 5° to 10°. This unit is Albian in age and is believed to correlate with the lower part the Nanushuk group (Tuktu member of the Umiat formation). It is inferred be the initial deposit of the Arctic Ocean, which came into existence as a deep-water body in Albian time. Thus the Barrow platform of Paleozoic iassic, Jurassic, and Early Cretaceous (Neocomian) time subsided to form the Arctic Ocean and no longer served as a source of sediments. pheral fault pattern delineated by geophysical work slightly east of the Barrow test wells suggest the presence of a cryptovolcanic structure. The age of the deformation cannot be stated with assurance, but it is likel at (1) the core of the structure, composed of basement rocks, was pushe

and (2) that sediments of the Namushuk group were deposited on basement

rocks of the core. This deformation may have been at the time of the

EARLY CRETACEOUS (LATE ALBIAN), LATE CRETACEOUS, AND TERTIARY HISTORY nterior and southern Alaska. -- With the Early Cretaceous orogeny the y of persistent intercontinental geosynclinal belts was ended (fig. In the younger strata there is no evidence of a distinct magmat t with contemporary lava and chert. In Albian time Alaska became differentiated into definable positive and negative tracts of erosion and deposition. These apparently were maintained through the remaining Cretaceous time and into Tertiary time.



Upper Cretaceous rocks, together with Lower Cretaceous rocks of late Albian age, constitute a stratigraphic sequence, locally more than 20,000 feet thick, that rests with marked angular discordance on earlier Cretayous and older rocks. These rocks were deposited in two northeast- to east-trending troughs in interior Alaska: (1) the northern or Koyul trough, lying between the Yukon River on the south and the Kobuk River and the Seward Peninsula on the north and west, and terminating to the east near Wiseman; and (2) the southern or Kuskokwim trough, which probably in the belt of Cretaceous rocks that crosses the Yukon-Tanana region from Hot Springs east to the international boundary. An emergent area be

early Brooks Range and a range to the south lying north of the present

the broad area of the present Yukon and Kuskokwim deltas, which may have been at the confluence of the two aforementioned troughs. Cretaceous rocks of the same age were deposited also in troughs in southern Alaska, where they are now exposed in great thickness in the northern part of the Alaska ange (Cantwell formation), in the Matanuska Valley (Matanuska formation), and elsewhere. In the Koyukuk and Kuskokwim troughs the lower part of the sequence of Lower Cretaceous (post-Albian ?) and Upper Cretaceous rocks is conglomeratic, and the remainder comprises chiefly sandstone, shale, and argillite with abundant pyroclastic detritus. The sedimentary rocks are primarily of marine graywacke type and were derived from nearby rising source areas.

Accumulation in the troughs was too rapid to permit much sorting by the seas. Thus the marine sandstone and conglomerate are muddy and of low permeability except locally where winnowed along shore lines. Nonmarine sediments, including beds of coal and winnowed near-shore sandstone, seem to be more common in the Koyukuk trough, where facies changes attending transgressive and regressive marine sedimentation are indicated. Sediments laid down in the Kuskokwim trough are predominantly of offshore marine facies; andesitic lavas are locally interbedded with the sediments. Nonmarine Early Tertiary sedimentary rocks, including shale, sandstone, conglomerate, lignite, and coal, were deposited in several basins in interior and southern Alaska; locally these rocks are a few thousand feet Numerous large masses of Tertiary to Recent lava flows and associted pyroclastic rocks are widely exposed in interior and southern Alaska; they constitute most of the rocks exposed in islands of the Bering Sea. At several places they rest with angular discordance on sediments of early

ertiary or pre-Tertiary age. Late Cretaceous and Tertiary orogenies strongly affected much of interior and southern Alaska, that is, the region south of the Brooks Range that formerly had been in the magmatic geosynclinal belt. Although there was local, low-grade metamorphism, the deformation was generally less inense than Jurassic and Early Cretaceous deformation; the associated intrusives are smaller and more commonly monzonitic, as compared with the large granitic intrusive bodies of Jurassic and Early Cretaceous time. The last stages of the orogeny and intrusion post-dated deposition of early Tertiary sediments. In addition to the silicic types, some of the intrusives cutting rocks as young as early Tertiary are mafic and ultramafic.

A study of the geologic literature on northeastern Siberia has revealed that the history of sedimentation, deformation, and intrusion in that region is similar to that of interior and southern Alaska. Thus it seems that both regions and the intervening intercontinental shelf area of the Bering Sea are part of the same geologic belt. Brooks Range and Arctic Slope .-- The Nanushuk and Colville groups of the Arctic Slope include Lower Cretaceous (late Albian) as well as Upper Cretaceous rocks. East of the longitude of Barrow these groups have a maximum thickness of about 10,000 feet; to the west the Nanushuk group thickens and the two groups together are probably more than 15,000 feet thick in the vicinity of Cape Beaufort. The Nanushuk and Colville groups consist of intertonguing marine and nonmarine sedimentary rocks comprising mostly shale, sandstone, conglomerate, bentonite, tuff, and coal; the sediments were delived from the south, from a land of moderate relief in the present Brooks Range area. This slowly emerging land occupied the site of the Early Cre-

taceous mountain range that had been the source of sediments of the Torok formation. The abundant quartz pebbles and cobbles in conglomerates of the two groups suggest that quartz veins were exposed to erosion in the source area. Quartz is generally rare in conglomerates of the underlying Torok and Okpikruak formations, and it is possible that the veins were injected at the time of the Early Cretaceous (Albian) orogeny. The inferred quartz veins may be genetically related to Lower Cretaceous (?) granitic intrusives n the Brooks Range, such as those exposed in the Baird Mountains. The quartz pebbles and cobbles, the coal, the intertonguing marine and nonmarine formations, and other features of the Nanushuk and Colville groups suggest that they represent "molasse"-type sedimentation, which norally follows a major orogeny and episode of intrusion. Although the conact between the Torok formation and the Nanushuk group represents a break in sedimentation within Albian time, it is relatively sharp and is one of the most easily recognized and persistent stratigraphic "horizons" in the Arctic Slope. The massive bluff-forming sandstone at the base of the Nanuhuk group overlies the thick shale of the Torok formation. It differs rom sandstone of the Torok formation, which occurs south of the contact area, in its better sorting, different mineralogy, more abundant fossils, and other features. The Torok formation represents marine sedimentation of orogenic type, whereas the Nanushuk and Colville groups represent deposition after the Albian orogeny under epeirogenic conditions, in part non-marine. Effects of Albian deformation, intense in the Brooks Range area, probably died out in the Torok formation. In the Torok formation-Nanushuk group contact area little or no evidence of angular discordance exists beween the Torok formation and the Nanushuk group; deposition there may have

Deposition north of the Brooks Range that resulted in the Nanushuk and Colville groups was different from that in troughs in interior and southern Alaska. Although the marine sediments are of a graywacke type, they differ rom the graywackes to the south. Sedimentation was not in a confined trough; there was no land to the north, and the depositional area was open the Arctic Ocean. Subsidence and accumulation probably was slower than n troughs of the unstable region to the south. General sorting of the ediments is believed to have been better; transgressive and regressive marine sediments were better developed; more sand was winnowed along shore lines and it probably is more porous and permeable; there are more indications of oil, and more coal is present. Thus in the Arctic Slope stratigraphic conditions seem better for oil and coal production, and structural onditions also are more favorable than in Cretaceous rocks of interior and

The Nanushuk and Colville groups have much in common, lithologically and paleontologically, with Cretaceous rocks of similar age in the Great lains region. One important difference in sedimentation, however, between he Great Plains and the Arctic Coastal Plain of Alaska is that, whereas in the Great Plains region a Cretaceous land existed to the east and was an auxiliary source of sediments, there is no evidence of a similar Cretaceous and north of the Arctic plain. The Arctic Ocean probably began to form in Albian time and very likely has been deepening through the remaining Creta-The Arctic Coastal Plain in Alaska is merely the exposed part of a

ea and northwest beneath the Chukchi Sea for many hundred miles off the coast of Siberia. Drilling in Alaska has indicated that the shelf and coastal plain are a product of sedimentation and are built mostly of Cretaceous rocks. Locally the gradient of the continental slope off northern Alaska is at least as steep as 6°; at the base of the slope depths as great as 1,500 fathoms are attained. During Cretaceous time the deep oceanic area subsided at about the same rate as the basement beneath the shelf and oastal plain but received little sediment compared with the latter regio It is thus topographically low because of relative lack of sedimentation. The depositional mechanism by which the shelf was built is indicate by seismic profiles of the Coastal Plain province, which show in the Creta ceous rocks certain units of generally north to northeast dips overlain and underlain by units of essentially flat-lying beds. Core data from test wells are in agreement with geophysical evidence in that cores from some units show dips of several degrees and evidence of subaqueous slump in the form of "curly bedding" and from other units show approximately horizontal strata. The theory of deltaic foreset bedding to explain these initial dips is not tenable because drilling has shown (1) that the dips are in fine-grained marine sediments probably deposited far offshore, and (2) that ypes of sediments normally associated with deltas are absent. The units initially dipping layers may represent stages of outbuilding of the Cretaceous continental shelf into deep water by progressive foreset deposition by turbidity currents that moved down the continental slope. Such an environment would have been unfavorable for bottom dwellers and may explain the

road, shallow continental shelf that extends north beneath the Beaufort

The first and major episode of the outward building of the shelf was in Albian time and involved deposition of the lower part of the Nanushuk group (Tuktu member), discussed above, which is characterized by initial dips, gen rally 5° to 10°. This came after a marked regional subsidence that droppe he Barrow platform below wave base and began the forming of the basin of he Arctic Ocean. By the end of deposition of the Tuktu member the process outward building had established a shelf in most of the present Coastal lain province; the strata of the succeeding Topagoruk member are flat ying, fossiliferous, include winnowed sands, and represent topset depos tion on the shelf during stages of slow subsidence and upbuilding about at wave base. When sediments of the Nanushuk group had been laid down the edge of the continental shelf probably stood in the vicinity of the present coast between Cape Simpson and the mouth of the Colville River. A large submarine canyon was carved in Cretaceous time in sediments of the Nanushuk group on the shelf edge at Simpson, and other canyons may be present elsewhere. Strata of the Colville group also represent topset continental shelf deposition in most of the area. There is, however, a thick zone of initial ly dipping marine rocks of the Colville group in the northern half of the Simpson peninsula. In later Cretaceous time, in the outward-building phase, sediments filled in the submarine canyon at Simpson and extended the continental shelf still farther northward. The edge of the continental shelf is now 80 to 90 miles north of the coast line between Barrow and the mouth of

the Colville River and probably attained this position through Late Cretaceous, Tertiary, and Quaternary outbuilding. In the Arctic Coastal Plain province east of the Colville River the Colville group is overlain by the Sagavanirktok formation. The redwood flora of the Sagavanirktok indicates early Tertiary age, and the formation consists of nonmarine red beds, claystone, sandstone, and conglomerate. A Tertiary orogeny, involving the Sagavanirktok formation, redeformed the Arctic Slope. In the Brooks Range area, where deformation was most inense and included imbricate thrusting, a new mountain range was produced. The east-striking cleavage in metamorphic rocks in the southern part of the Range formed either at this time or during the Early Cretaceous deformation, the grain of which also strikes east. The cleavage is best developed in a thick sequence that probably includes both lower Paleozoic and pre-Cambrian rocks. The part believed to be pre-Cambrian is more highly metamorphosed

and also has a north-striking earlier cleavage; the Brooks Range area prob

bly was not strongly deformed between pre-Cambrian and Early Cretaceous

In the southern part of the Arctic Foothills province folding and ting were complex, and in the northern part of this province the Nanu shuk and Colville groups were extensively deformed in Appalachian-type folds that strike approximately east. The Tertiary orogeny reached farther orth than the Early Cretaceous orogeny and gently folded the southern part of the Coastal Plain province. The formations in the northern part of the Coastal Plain, however, were not compressionally folded. Structures deected by seismic work in the Coastal Plain have little relief and closure ovements culminating in the Tertiary orogeny may have begun in Cretaceous time. Evidence is accumulating that some of the folds in the Foothills province were growing during deposition of sediments of the Nanushuk group At the crest of the Umiat anticline the Topagoruk member of the Umiat formation is 1,000 to 1,500 feet thinner than would be expected, which sugests either local erosion or lack of deposition with stratigraphic convergence over the axis (fig. 5, B-B').

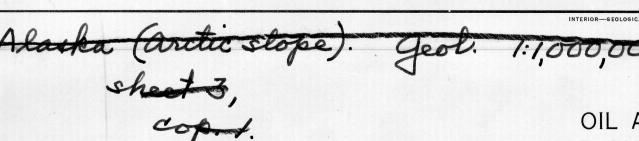
Arctic Foothills province; rather it appears to have been a structurally positive feature throughout Mesozoic time. Mesozoic units thin or wedge ut over this structure. It and the associated cryptovolcanic (?) struc ture near Barrow may be related to some feature of basement rocks. Intrusive and extrusive igneous rocks of Cretaceous and Cenozoic ag common in interior and southern Alaska have not been found in the Arctic Slope region. The large positive magnetic anomalies in the Coastal Plat province are believed to be caused by susceptibility differences within asement rocks and to represent pre-Cambrian intrusives. The granitic inrusives and mineralization in the Canning River region may likewise be

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